TECHNICAL-ECONOMICAL EVALUATION OF DIFFERENT SCENARIOS FOR THE INTEGRATION OF DECENTRALIZED RENEWABLE GENERATION INTO RURAL 110 KV NETWORKS

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ABSTRACT

Due to the change of the public power supply system, the requirements of rural distribution networks will change significantly. The high degree of decentralized renewable energy leads to higher equipment loading and reverse power flows. The future tasks thus require new measures.
This paper describes the development of different forecast scenarios for decentralized generation and the study of the resulting challenges of integration in a rural 110 kV network. At the beginning, future scenarios are developed under consideration of various existing studies. The different future expectations are then implemented in a 110 kV PSS®SINCAL network model, so that a future network scenario in 2050 can be evaluated. The technical evaluation is made by performing load flow calculations. Different network reconfigurations are analyzed and four solutions are developed.
For the economical evaluation, the base scenario is expanded and four more scenarios are developed. Finally, an economical analysis of different variants and scenarios makes it possible to identify future needs.

INTRODUCTION

For more than a decade the German electrical power system has been in transition from centralized conventional generation based on coal and nuclear towards a decentralized renewable generation scenario. This transition of the energy system is politically motivated to reduce the carbon footprint of energy consumption. After the rapid increase of the installed base of wind power and biogas generation during the first phase of transition, the integration of photovoltaic (PV) generation into the distribution grids has now reached a critical state. The ongoing installation of renewables will finally lead to the need for massive network extensions.
New challenges arise from the change of the central power generation scenario towards a decentralized power generation scenario. Two aspects have been considered for an analysis of the changed distribution grid requirements:

- Old conventional generation units will be taken out of service
- New distributed generation will increase the maximum loading of equipment during extreme weather conditions.

These new operating modes affect the load flow extremely and are a new challenge to the structure of electricity grids, because these grids were not dimensioned and planned for a decentralized power supply. Measures are needed to secure a reliable network operation and to ensure sustainable investments.

Development of Scenarios

Different studies have been considered to model the expected future renewable feed-ins. In particular, the targets for 2050 of the German government [1] are the most important orientation. This political driven document shows the development of renewable and decentralized generation on a general basis. The consequence and impacts are also shown by DLR [2]. This study shows a deeper view into the realization of the German targets.
The studies show the development of renewable generation in Germany, but did not directly focus on the location within the country. Due to the type of generation units being considered, it has expected that nearly 100% will be installed in rural areas as larger cities do not offer the possibility for wind, biomass and the high degree of PV generation. Finally the development of scenarios was based on the following assumptions:

- The load will be constant until 2050
- 50% of the load is in rural areas
- 93% of onshore-installed renewable generation will be erected in rural areas
- The installed renewable generation is about 1.5 times of the maximum German load

Based on these assumptions, the future base scenario was created (figure 1):

The installed power in rural distribution networks is three times the actual load:

$$P_{re} = 3.00 \cdot P_{load}$$

With P_{re}: Installed renewable energy capacity
P_{load}: Maximum load demand

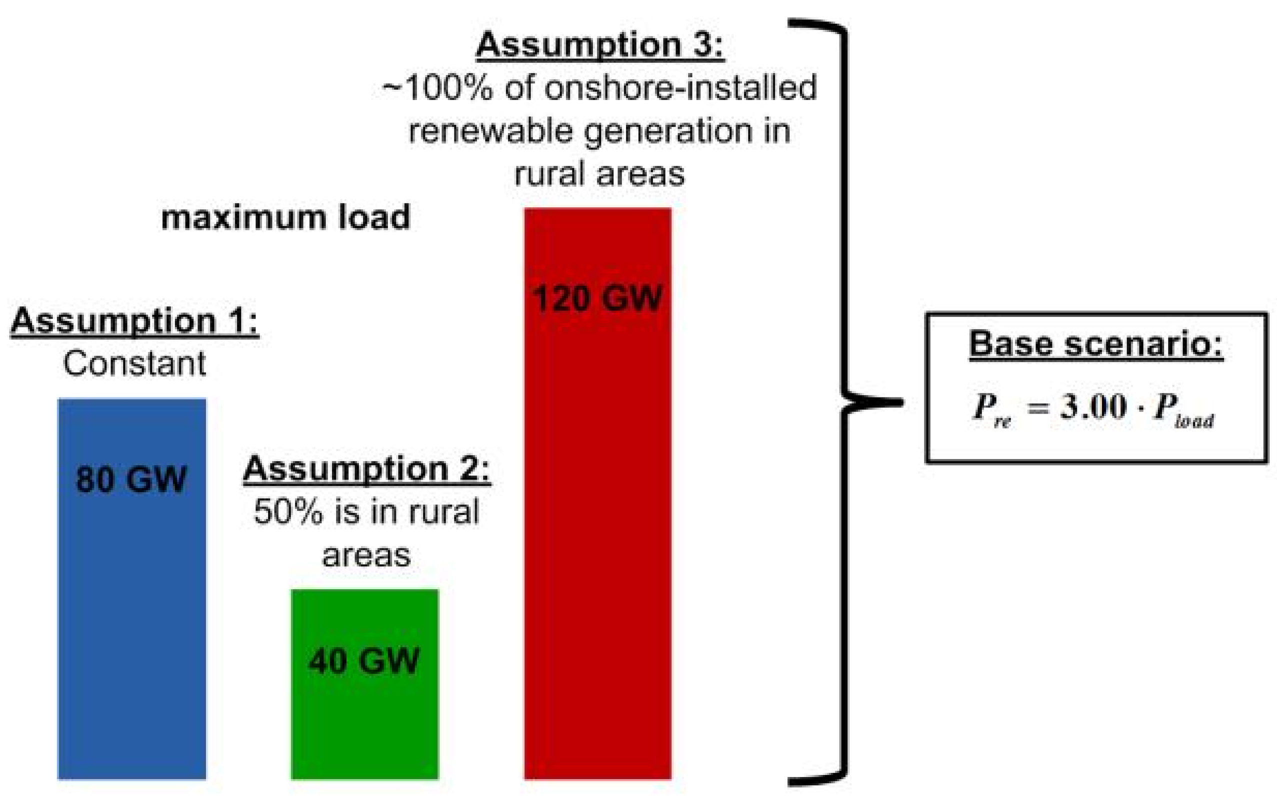

Figure 1 - Graphical representation of creation of base scenario

The installed renewable energies are photovoltaic, onshore-wind power and biomass. Any other types can be neglected. The determined installed power

is thus divided amongst the three different distribution generation types. Here the part of photovoltaic is 52%, onshore-wind power 40% and generation with biomass 8% [2]. The studies consider this distribution of generator types for all variants.
As mentioned, the distribution of generation has been coupled to the maximum consumption. The factor 3 is used if the generation units are distributed according to the load. It is clear that it will definitely not be realistic to reach a homogeneous distribution of generation in all areas of Germany.
It is difficult to examine the economic influence by considering only one scenario. So the base scenario is expanded and the total scenarios are increased to five with different feed-in values:

- $P_{re} = 3.00 \cdot P_{load}$
- $P_{re} = 3.25 \cdot P_{load}$
- $P_{re} = 3.50 \cdot P_{load}$
- $P_{re} = 3.75 \cdot P_{load}$
- $P_{re} = 4.00 \cdot P_{load}$

For a real representation existing curves for wind speeds and solar radiation [3] as well as load curves have been used to model generation and load curves. This allows to carry out simulations over a long period. In this study, a time period of one month (here: June) was used because this month represents an exemplary sunny month in the summer.
The different scenarios and the generation and load profiles have been allowed to identify critical scenarios from the behavior of load and generation in the past.

NETWORK

The considered network is an existing rural 110 kV distribution network. It shows the impact of two future changes:

- The shutdown of a power plant in an exposed network location and
- The increase of wind, PV and biomass generation in a rural area.

This network is fed from one 380 kV/110 kV and three 220 kV/110 kV transformers and has 20 substations with one load. The maximum load is 534 MW and the total overhead line length of the 110 kV network is presently 319 km. Figure 2 shows the examined network.
Due to the shutdown of the power plant the network needs to be upgraded to ensure a reliable supply. Due to the increasing distributed generation, the load flow will reverse and during low load the overloading of overhead lines will be expected. In this case, the former strong feed-in of the power plant is in the middle of the network and the direct connection to the 220 kV/380 kV networks is not strong enough to transport the renewable energy to the network. The low impedance within the 110 kV network towards the former power plant feed-in leads to high power flow towards this location.

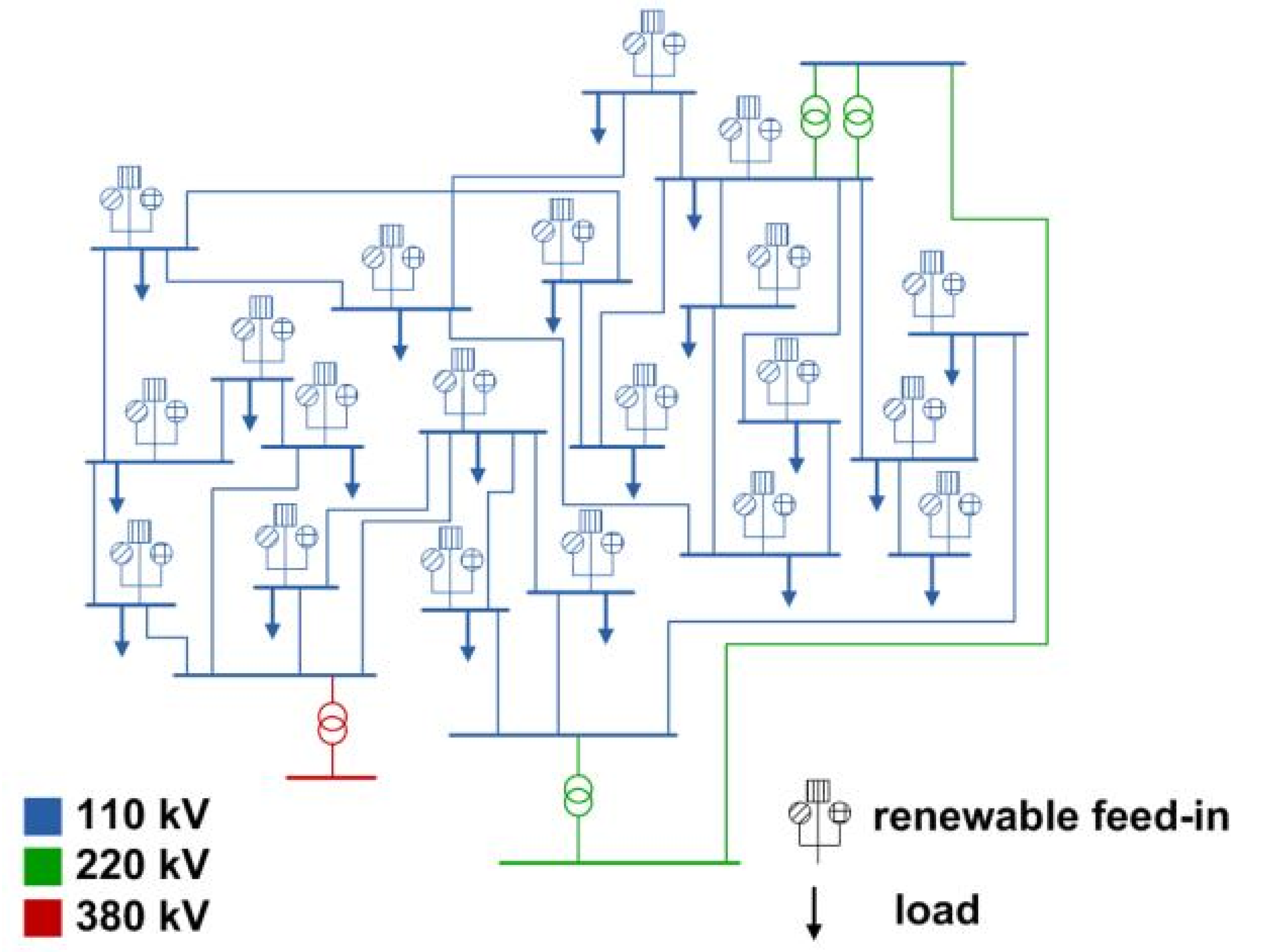

Figure 2 - Schematic representation of the examined network

For the case study, the different scenarios are implemented so that a network topology of 2050 is available. The implementation is made by allocating the feed-ins - photovoltaic, onshore-wind and biomass - to one substation. Thereby the individual feed-ins have different powers, which are stochastically allocated. The results are five different network configurations, which can be analyzed and evaluated.

CASE STUDY

The described scenarios have been modeled to carry out load flow calculations. As expected the utilization of the equipment rises with increasing power feed-in of renewable sources and parts of the existing equipment are overloaded.

Examined planning variants

For all simulations the time of the highest load was used. To avoid overload, different variants of network improvement have been compiled and analyzed. The different variants of network improvement are described and explained as follows:

Variant 1: Conventional grid reinforcement
In this variant, the overloaded equipment is replaced by equipment with higher ratings or additional equipment.

- All overloaded cables / lines get a parallel cable system for reinforcement
- Overloaded transformers are replaced by transformers with a higher rated power.

Variant 2: Specifically overload
In the second variant the equipment can be operated with overload up to 120% of its rated values. If loading exceeds 120% the measures of variant 1 are carried out. In some cases forced cooling of transformers had been taken into consideration.

Variant 3: Reduced feed-in with storage system

Variant 3 shows the reduction of the generation distributions or the shutdown of all generation units in the whole system for a short period of time during extreme feed-in. This measure performed decentralized, directly at the critical substations. The excess power thus does not feed-in the network and an overload can be avoided. The reduced part of energy is stored and can be used during times of high load or times of low generation.

For the examination of this variant the excess power of the network was determined with the rated power of the transformers and its overload. Here the maximum energy is calculated from the overload period and the excess power. The examined storage systems are lithium-ion (Li-Ion) and hydrogen (H_2).

Variant 4: Curtailment of renewable feed-in

The fourth variant demonstrates the limitation of the maximum renewable feed-in to 70% of the rated power. In case of higher generation the units will be limited or a part of the energy has to be stored.

For the implementation of this variant the feed-in curves of photovoltaic and wind-power is limited to a factor of 0.7. The biomass in-feeders are further run at 100%. The determination of the excess power and the analysis of the storage systems are considered like in variant 3.

TECHNICAL EVALUATION

In the first step of the technical evaluation, load profile calculations were performed. Here the described generation and load curves were used to find the highest network stress (worst-case). Afterwards the load and generation parameters have been fixed to carry out all further evaluations without load profile calculations. This worst-case scenario is not during low load period but during day-time with high PV and wind feed-in.

The analysis of the load flow calculation of variant 1 and 2 shows several overloaded equipment. Table 1 demonstrates the necessary reinforcement of the two variants.

Table 1 - Measures in variant 1 and 2

Var.	Scenario	Cable / Lines	Replaced transformers
1	3.00x	2 additional - 9 km	4
	3.25x	2 additional - 9 km	
	3.50x	5 additional - 45 km	
	3.75x	6 additional - 57 km	
	4.00x	7 additional - 69 km	
2	3.00x	1 additional – 4 km	4 ventilators
	3.25x	1 additional - 4 km	1 3 ventilators
	3.50x	2 additional - 9 km	
	3.75x	2 additional - 9 km	4
	4.00x	5 additional - 45 km	

The findings of the conventional grid reinforcements show the necessity of an increasing number of measures related to the increasing number of installed renewable energies. At the beginning, the costs for network extension is still very low but increase extremely after a certain point of penetration has been reached.

The comparison of variant 1 and 2 shows that in both cases a massive network extension has to be carried out. In variant 2 the number of reinforcement are smaller at the beginning but with rising feed-in this advantage disappears.

Variant 3 and 4 consider the excess power in different scenarios. The limited power feed-in is determined so that a proper network operation is possible and the need for storage can be calculated. Table 2 illustrates the separated power and energy.

Table 2 - Excess power and calculated energy in planning variants 3 and 4

Var.	Scenario	P_{max} [MW]	W_{max} [MWh]
3	3.00x	93	209
	3.25x	215	591
	3.50x	355	1331
	3.75x	503	2011
	4.00x	683	2903
4	3.00x	---	---
	3.25x	6	13
	3.50x	70	192
	3.75x	172	560
	4.00x	285	1067

The increase of excess power is a non-linear function according to the increase of generation units. The reduction of power feed-in of variant 4 is less than the excess power in variant 3. This demonstrates the positive influence of the tailored limitation of renewable feed-in and it shows that this is an efficient measure to reduce a massive network extension.

ECONOMICAL EVALUATION

The different measures of the technical assessment were evaluated by analyzing the several feed-in capacity scenarios. For the economical study the total costs for the individual variants and scenarios were calculated. In consideration of the investment and operating costs the economic boundary conditions could be evaluated.

For the investment costs calculation prices are used. The operating costs are considered as percentage of the investment costs for simplification. The cost comparison is made by the cash value method, in which the present day is considered as the reference.

First variant 1 and 2 are compared. The results are shown in figure 3.

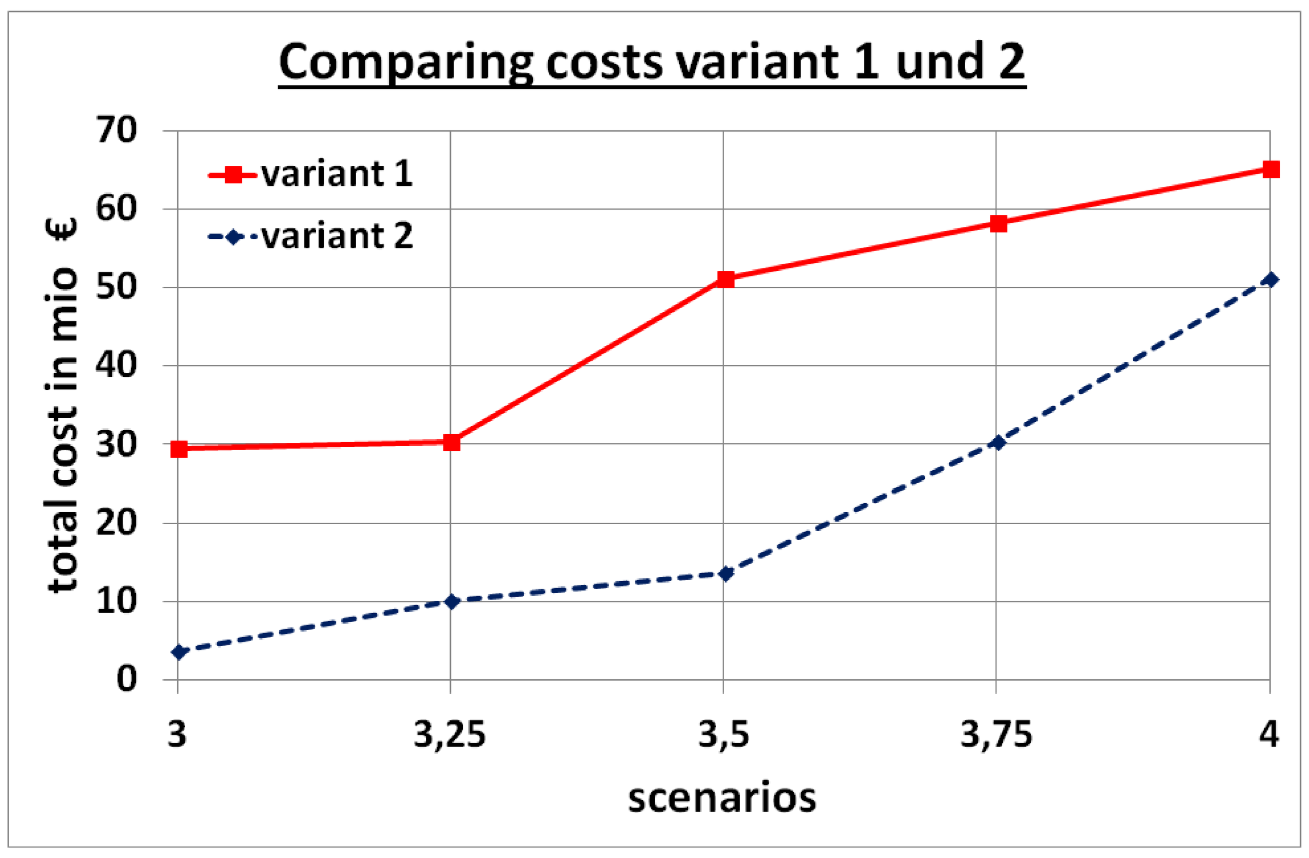

Figure 3 - Comparing costs variant 1 and 2

The evaluation of variant 1 and 2 shows that with increasing renewable feed-in the total costs grow. For low feed-in overloading of equipment is an efficient measure to save costs, because the investment costs are much lower and the network can be operated after a minimum of network extensions. The costs of variant 2 at scenario $3.75 \cdot P_{load}$ are equal to the costs of the scenario $3.25 \cdot P_{load}$ of variant 1. Therefore investment can be shifted into the future. With higher degree of decentralized generation this advantage disappears, and as seen for variant 2 massive extensions become necessary. This is explained by the increasing number of high loading units and the shrinking possibilities of overloading. Most of the units will now over exceed the given limit of 120% equipment loading.
The results show that it is recommended to start for low feed-in with variant 2 (overloading) due to lower investment cost. For very high feed-in a massive extension is inevitable.

Secondly variant 3 and 4 with the two storage systems Li-Ion and hydrogen were compared. The results are seen in figure 4.

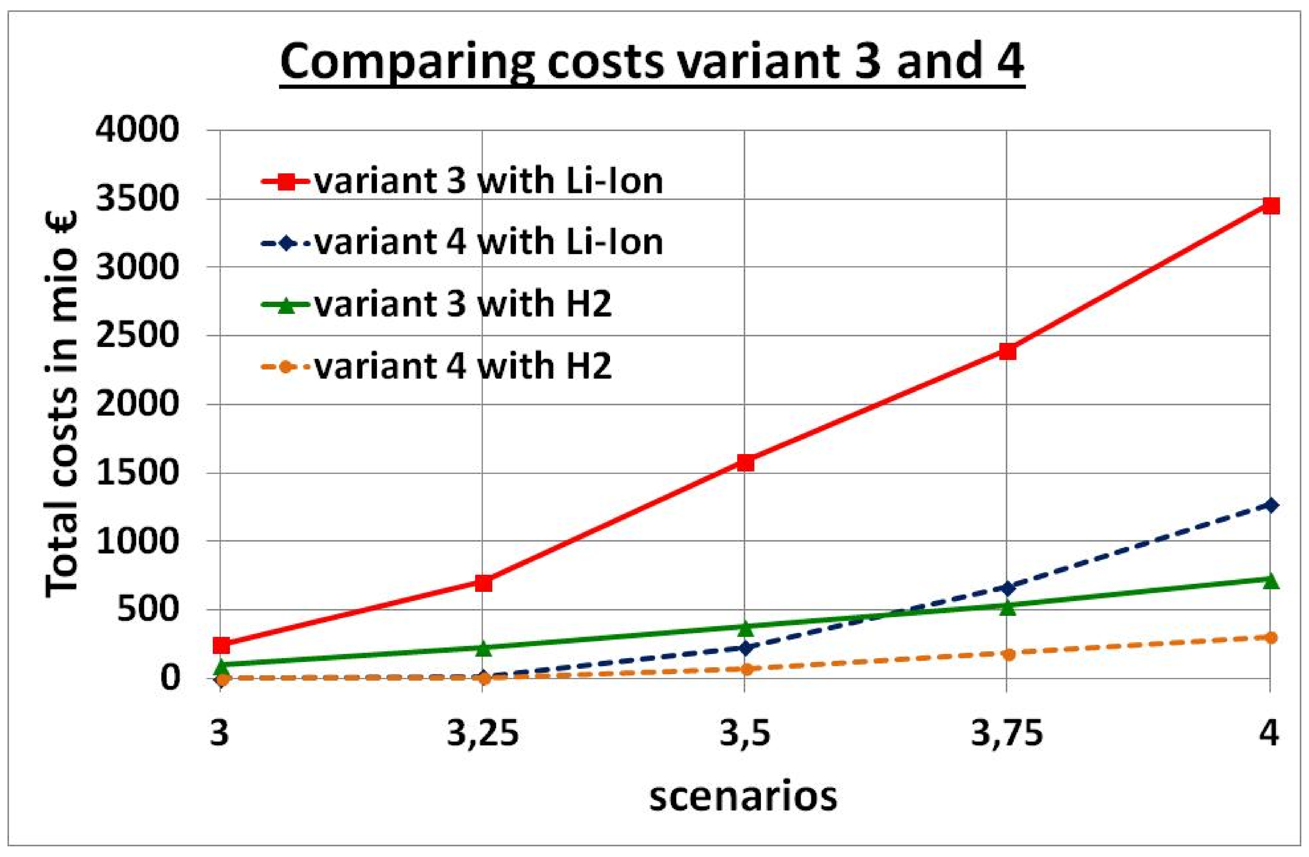

Figure 4 - Comparing costs variant 3 and 4

The assessment demonstrates that the costs for Li-Ion are more expensive than the costs for H_2. The total costs of the Li-Ion system in variant 3 are already blow up for the scenario $3.25 \cdot P_{load}$. The costs for hydrogen also increase, but not as strongly like for Li-Ion. So the hydrogen storage represents the cheaper system at high generation distribution, but the measure of variant 3 represents a very expensive possibility for a proper network operation.

The comparison of variant 3 and 4 shows the positive influence of the limitation. The excess power in variant 4 is much lower than in variant 3 and so the storage capacity and the total costs decrease significantly. This is comprehensible, because by the limitation a part of the feed-in is blocked and reduces the stress of the network.
The comparison demonstrates that the measure of limitation has a high cost saving potential. The total costs are reduced significantly by the lower storage capacity because of the reduced feed-in.
Altogether the investment and the operating costs of both storage systems are very high and reach values in a range of a billion Euros. Thus, the individual costs cannot be financed only by savings in the high voltage level. In fact, the total costs have to split in the several voltage levels or stakeholders.

CONCLUSIONS

The case study illustrates that conventional grid reinforcement, reduced feed-in and storage are different technical solutions to control network overloads. The cost advantages of overload equipment decrease with the increasing generation distribution and the network extensions increase much stronger from a certain power. The different measures (variants) allow a safe network operation, but the storage requirements and the reduced feed-in rise disproportionately.
In conclusion the evaluation shows that the conventional network extension is the cheapest possibility for the full use of the renewable generation. The application of storage systems is worthwhile, when other voltage levels assume costs. Finally, the curtailment of renewable feed-in prevents measures of reinforcement with low energetic losses.

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